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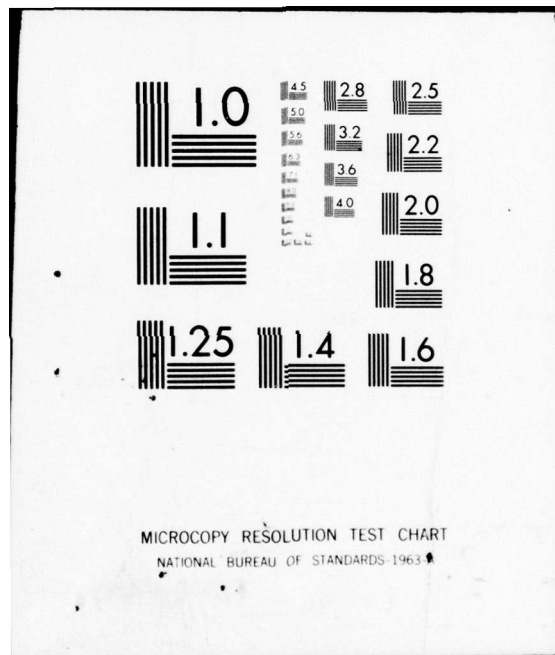
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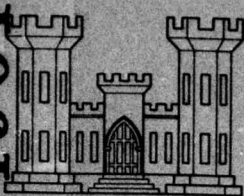
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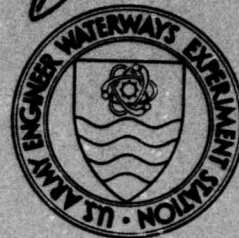


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# DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-24



## AQUATIC DISPOSAL FIELD INVESTIGATIONS DUWAMISH WATERWAY DISPOSAL SITE PUGET SOUND, WASHINGTON

### APPENDIX C: EFFECTS OF DREDGED MATERIAL DISPOSAL ON THE CONCENTRATION OF MERCURY AND CHROMIUM IN SEVERAL SPECIES OF MARINE ANIMALS

by

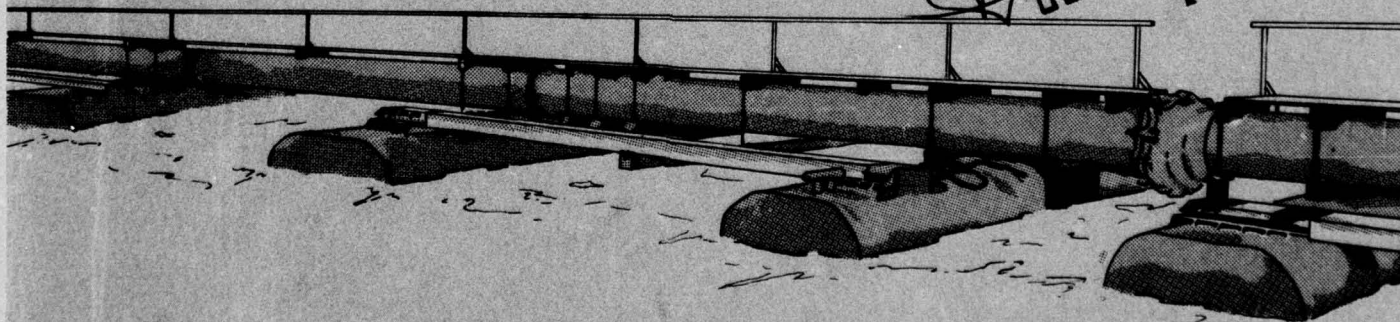
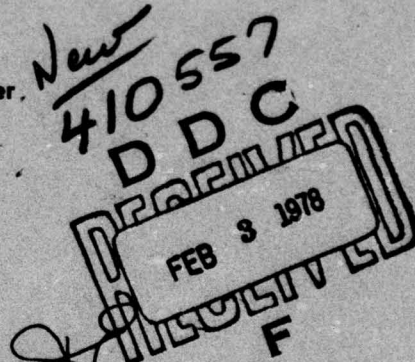
Fuad M. Teeny, Alice S. Hall

3 Northwest and Alaska Fisheries Center

2 National Marine Fisheries Service  
Seattle, Washington 98104

November 1977  
Final Report

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Under Interagency Agreement No. WESRF 76 - 90  
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AQUATIC DISPOSAL FIELD INVESTIGATIONS  
DUWAMISH WATERWAY DISPOSAL SITE  
PUGET SOUND, WASHINGTON

- Appendix A: Effects of Dredged Material Disposal on Demersal Fish and Shellfish in Elliott Bay, Seattle, Washington
- Appendix B: Role of Disposal of PCB-Contaminated Sediment in the Accumulation of PCB's by Marine Animals
- Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals
- Appendix D: Chemical and Physical Analyses of Water and Sediment in Relation to Disposal of Dredged Material in Elliott Bay
- Appendix E: Release and Distribution of Polychlorinated Biphenyls Induced by Open-Water Dredge Disposal Activities
- Appendix F: Recolonization of Benthic Macrofauna over a Deep-Water Disposal Site
- Appendix G: Benthic Community Structural Changes Resulting from Dredged Material Disposal, Elliott Bay Disposal Site

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SUBJECT: Transmittal of Technical Report D-77-24 (Appendix C)

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (work units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations (ADFI), of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 1A is a part of the Environmental Impacts and Criteria Development Project (EICDP), which has as a general objective determination of the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent that such sites are recolonized by benthic flora and fauna. The study reported on herein was an integral part of a series of research contracts jointly developed to achieve the EICDP general objective at the Duwamish Waterway Disposal Site, one of five study sites located in several geographical regions of the United States. Consequently, this report presents results and interpretations of but one of several closely interrelated efforts and should be used only in conjunction with and consideration of the other related reports for this site.

2. This report, Appendix C: Effects of Dredged Material Disposal on the Concentration of Mercury and Chromium in Several Species of Marine Animals, is one of seven contractor-prepared appendices published as Waterways Experiment Station Technical Report D-77-24 entitled: Aquatic Disposal Field Investigations, Duwamish Waterway Disposal Site, Puget Sound, Washington. The titles of all contractor-prepared appendices of this series are listed on the inside front cover of this report. The main report will provide additional results, interpretations, and conclusions not found in the individual appendices and will provide a comprehensive summary and synthesis overview of the entire project.

3. The purpose of this study, conducted as Work Unit 1A10B, was to determine the effect of open-water disposal of dredged material from the Duwamish Waterway into Elliott Bay on uptake of mercury and chromium by spot shrimp, sea cucumber, mussel, English sole, and Alaska and Oregon pink shrimp. Organisms were collected over a period of nine months from two environmentally similar sites in Elliott Bay, a disposal site and a control site. Tissue analyses of whole organisms for mercury and chromium revealed no significant differences between the two sites before or after the disposal operation. A conclusion of this report, based on

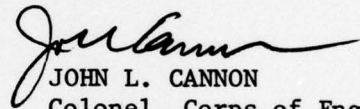
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the data presented, was that the disposal operation had no apparent effect upon the mercury and chromium concentrations in the five species studied.

4. The results of this study are important in determining placement of dredged material for open-water disposal. Referenced studies, as well as the ones summarized in this report, will aid in determining the optimum disposal conditions and site selection for either the dispersion of the material from the dump site or for its retention within the confines of the site, whichever is preferred for maximum environmental protection at a given site.



JOHN L. CANNON

Colonel, Corps of Engineers  
Commander and Director

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21. ABSTRACT (Continue on reverse side if necessary and identify by block number) Specimens of five species of marine organisms indigenous to Puget Sound were collected over a period of nine months for mercury and chromium analysis. The specimens were collected from two environmentally similar sites in Elliott Bay, the disposal site for "polluted" dredged material from the Duwamish Waterway and a reference or control site. Mercury and chromium concentrations in English sole ( <i>Parophrys vetulus</i> ), (Continued)			

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20. ABSTRACT (Continued)

Alaska and Oregon pink shrimp (Pandalus borealis and P. jordani), spot shrimp (Pandalus platyceros), sea cucumber (Parastichopus californicus), and mussel (Mytilus edulis) were not significantly different between the two sites. In all samples, the levels of mercury and chromium were low and did not exceed 0.10 ppm for mercury and 0.91 ppm for chromium. These data suggest that the disposal operation had no apparent effect upon the mercury and chromium concentrations in the five species of organisms studied.

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## EXECUTIVE SUMMARY

A study was made on effects of open-water disposal of dredged material from the Duwamish Waterway into Elliott Bay on concentrations of mercury and chromium in five species of marine animals indigenous to Puget Sound. A disposal site and a control site (west reference) were chosen as the test areas in Elliott Bay.

Spot shrimp (Pandalus platyceros) were transplanted to the study sites during the disposal operation to study the effects of maximal impact of exposure to the dredged material. Mussels (Mytilus edulis) and sea cucumbers (Parastichopus californicus) were transplanted after disposal and were exposed for up to three weeks in cages set on the bottom of the bay. English sole (Parophrys vetulus) and Alaska pink shrimp (Pandalus borealis) were collected at the two sites before and after exposure for up to 39 weeks. Oregon pink shrimp (Pandalus jordani) were collected after disposal from the reference site only.

No significant changes were noted in concentrations of mercury or chromium in test animals as a result of the open-water disposal of the contaminated dredged material. The levels of these two elements were low and did not exceed 0.07 ppm mercury and 0.68 ppm chromium in spot shrimp; 0.03 ppm mercury and 0.51 ppm chromium in mussels; 0.02 ppm mercury and 0.36 ppm chromium in sea cucumbers; 0.10 ppm mercury and 0.62 ppm chromium in English sole; and 0.08 ppm mercury and 0.91 ppm chromium in pink shrimp.

Generally, the mercury and chromium content of the specimens decreased slightly with exposure time. These observations suggest that open-water disposal of the dredged material had no effect upon the mercury and chromium concentrations of the five species studied.

## PREFACE

This report presents the results of a study to determine the effects of open-water disposal of dredged material from the Duwamish Waterway into Elliott Bay upon the concentration of mercury and chromium in five species of marine animals indigenous to Puget Sound.

The study was prepared for the Office, Chief of Engineers, and supported by the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Effects Laboratory (EEL), Vicksburg, Mississippi, under Interagency Agreement No. WESRF 76-90 to the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Washington. The report forms part of the EEL Dredged Material Research Program (DMRP).

The report was written by Fuad M. Teeny and Alice S. Hall of the Utilization Research Division, Northwest and Alaska Fisheries Center. Chemical analyses for mercury and chromium were conducted by the authors. The samples for this study were subsamples of those used by Dr. Virginia F. Stout for PCB analysis (Appendix B). Virginia Stout, Laura Lewis, and Robert Shepp of this Division of the National Marine Fisheries Service prepared the samples and recorded all physical data. The specimens were provided by George Snyder, John R. Hughes, Warren E. Ames, Herbert Sanborn, Benjamin Patten, and Suanne Y. Smith of the Environmental Conservation Division of the Northwest and Alaska Fisheries Center.

The study was conducted under the direction of the following EEL personnel: Dr. R. M. Engler, Environmental Impacts and Criteria Development Project, Project Manager; J. R. Reese and Jeffrey H. Johnson, Site Managers; and Dr. Henry E. Tatem who coordinated the site reports. The study was under the general supervision of Dr. John Harrison, Chief, EEL.

Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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AQUATIC DISPOSAL FIELD INVESTIGATIONS  
DUWAMISH WATERWAY DISPOSAL SITE, PUGET SOUND, WASHINGTON

APPENDIX C: EFFECTS OF DREDGED MATERIAL DISPOSAL  
ON THE CONCENTRATION OF MERCURY AND CHROMIUM  
IN SEVERAL SPECIES OF MARINE ANIMALS

Introduction

1. Puget Sound is a relatively unpolluted body of water in the State of Washington, whereas the Duwamish Waterway (a river that empties into Elliott Bay, Seattle's harbor in Puget Sound) is polluted. This waterway is fronted for several miles by factories and the dry docks of several shipyards; thus, sediment in the Duwamish channel is subject to disposal of industrial wastes that may contain heavy metals such as mercury and chromium. In contrast with the open ocean, sedimentation in estuaries may be extremely rapid.<sup>1</sup> As a river enters an estuary, its rate of flow is reduced and suspended sediments are deposited. The increase in the salt concentration as the fresh water mixes with seawater may also cause precipitation of heavy metals. There is evidence that metals that are adsorbed on or incorporated into particles can, under suitable conditions, be desorbed or remobilized.<sup>2,3</sup> In this way they can become available for circulation in the environment and possibly incorporation into marine animals by any of several routes.

2. The United States Army Corps of Engineers maintenance dredging of the Duwamish Waterway in 1976 was coupled with an extensive research program to obtain more definitive information on several environmental aspects of the dredging operation. This portion of the program was initiated to determine the effects of discharging dredged material from the Duwamish Waterway into Elliott Bay upon the uptake of mercury and chromium by several species of marine animals that were indigenous to Puget Sound. Studies of the levels of trace metals in the sediments and water are the subject of another part of the total program.

3. Mercury and chromium are used extensively in industry and in agriculture. In man's use of these two elements and their compounds, large quantities have been discharged into the environment, and much of it ends up in waterways. In the 1950's and 1960's, several outbreaks of mercury poisoning took place among people who consumed fish and shellfish harvested from mercury contaminated waters and bread prepared from wheat seeds heavily contaminated with mercury.<sup>4,5</sup> Birds and other wildlife have died from eating seeds treated with a mercury based fungicide.<sup>6</sup> Researchers studied the biological methylation of mercury in aquatic organisms and found that wastes containing mercury discharged into the water can be converted into methyl and dimethyl mercury by microorganisms present in the sediment.<sup>7</sup> The dimethyl mercury is volatile and passes into the water column from the sediment and may be converted into methyl mercury at low pH. Methyl mercury is soluble in water and is concentrated by algae, fish, and other marine organisms, and through the food chain, finally by man.<sup>8</sup>

4. Chromium is one of the heavy metals essential for living organisms.<sup>9</sup> Chromium concentration in marine organisms usually ranges from 0.1 to 2.0 ppm, although up to 14.7 ppm were found in the polychaete Aphrodite aculeata.<sup>10</sup> An exceptionally high value of 144 ppm was found in the ascidian Eudistoma ritteri.<sup>11</sup> The lethal toxicity for the element ranged between 33 and 100 ppm for fish Angonus cataphractus, 100-330 ppm for the mollusk Cardium edule, and approximately 100 ppm for the crustacean Crangon crangon.<sup>12</sup> Chromium is reported to be readily absorbed in the chromate form, but little is absorbed in the chromic form.<sup>13</sup> Chromium enters the marine environment principally associated with particulate matter. Particulate matter suspended in the water is available for ingestion with food and water by marine organisms.<sup>14</sup> The element may also find its way into the animals through the general body surface<sup>15</sup> or through special areas such as gills.<sup>16</sup>

5. Concentrations of trace metals in marine organisms tend to reflect those in the marine environment.<sup>17,18</sup> Various amounts of trace metals occur naturally in marine sediments that are not considered

polluted. Disposal of dredged material in the marine environment may increase the amount of both soluble compounds and suspended sediments containing metals at elevated levels which may affect organisms.

6. This research was designed to determine what effect, if any, open-water disposal of dredged material from the Duwamish Waterway into Elliott Bay would have on the uptake of mercury and chromium by: spot shrimp (Pandalus platyceros), sea cucumber (Parastichopus californicus), mussel (Mytilus edulis), English sole (Parophrys vetulus), Alaska pink shrimp (Pandalus borealis), and Oregon pink shrimp (Pandalus jordani).

### Materials and Methods

#### Sampling sites

7. Specimens were collected from two designated sites: one was the site where the dredged material was disposed (disposal site), and the other was a site not affected by disposal (west reference), but environmentally similar to the disposal site. The disposal site consisted of an area 610 x 610 m (2000 X 2000 ft) off Harbor Island at the mouth of the Duwamish Waterway at 47°35'41"N, 122°21'42"W in approximately 55-61 m (180-200 ft) of water. The west reference site was located approximately 1200 m (3920 ft) to the southwest of the disposal site at 47°35'32"N, 122°22'37"W.

#### Specimens

8. Spot shrimp. The specimens were caught near Whitney Point and the predisposal specimens were processed for trace metal analysis. The remaining animals were immediately transferred to the disposal and west reference sites during the disposal operation. These animals were held in vinyl-coated wire mesh cages (92 X 92 X 46 cm) and set on the bottom of the bay. After 3 days exposure, only the animals at the disposal site were recovered, while those at the west reference site were lost. New specimens were transferred from Whitney Point to both areas. After 3

days exposure, the samples at the disposal site were recovered, but the ones held at the west reference site were not found until 4 days later (7 days total exposure time).

9. Sea cucumbers and mussels. The sea cucumbers were collected at Agate Pass and the mussels at Mukilteo. The predisposal specimens were processed for trace metal analysis and the remaining animals were transferred to the test areas immediately after disposal operations ceased. The postdisposal specimens were held in uncoated wire mesh cages (224 X 86.4 X 86.4 cm) and set on the bottom of the bay. Specimens were removed at 1, 2, and 3 weeks after exposure.

10. English sole. The specimens were collected before and 2 weeks after disposal at the 2 test sites. Additional specimens were collected from the west reference site at 5 and 39 weeks after disposal.

11. Alaska pink shrimp. The specimens were collected at both sites before disposal and at 2, 5, 14, 27, and 39 weeks after disposal. The predisposal samples from the disposal site consisted of a mixture of Oregon and Alaska pink shrimp but were predominately Alaska pink shrimp.

12. Oregon pink shrimp. Specimens were collected at 5, 27, and 39 weeks from the west reference site only.

#### Sample preparation

13. English sole (5 fish per sample) consisted of the whole bodies less stomach contents; sea cucumbers (3 per sample) of whole bodies less excess water and intestine contents; mussels (30 per sample) of whole bodies less shells; spot shrimp (10 per sample) and pink shrimp (14 per sample) of whole bodies including shell. The composites were ground and thoroughly mixed prior to subsampling for chemical analysis.

#### Analytical methods

14. Mercury. Total mercury was determined by the Vanadium Pentoxide method of the U.S. Food and Drug Administration.<sup>19</sup> This method uses a mixture of sulfuric and nitric acids with vanadium pentoxide for digestion of the sample. A stannous chloride solution is added

to the digest to reduce mercury to the elemental state followed by immediate aeration in a closed system. The mercury vapor is measured by atomic absorption spectroscopy using a Perkin Elmer Model 403 spectrophotometer. Results are stated in parts per million (ppm) on a wet-weight basis. All samples were subjected to single analysis and 18 samples (15 percent) were duplicated. Differences between duplicates did not exceed 0.01 ppm (Table C1).

15. Chromium. The samples were dried and charred under infrared heat lamps prior to ashing in a muffle furnace at a maximum temperature of 450°C. The ash was dissolved in 2 ml concentrated nitric acid and brought to volume with deionized water in a 50-ml flask. Final measurement was by flame atomic absorption spectroscopy using a semi-automated Perkin Elmer Model 303 spectrophotometer which was interfaced to a programmable Wang calculator.<sup>20</sup> Results are stated in parts per million (ppm) on a wet-weight basis. All samples were subjected to single analysis and 18 samples (15 percent) were duplicated. Differences between duplicates did not exceed 0.08 ppm (Table C2).

### Results and Discussion

#### Spot shrimp

16. The mercury content of spot shrimp ranged between 0.06 and 0.08 ppm (Table C3). The mean mercury level (background) prior to disposal was 0.06 ppm as compared to 0.06 and 0.07 ppm after 3 and 7 days exposure at the disposal and west reference sites, respectively. These data did not indicate any changes in the mercury content of spot shrimp.

17. The chromium content ranged between 0.55 and 0.68 ppm (Table C3). The mean chromium level prior to disposal was 0.64 ppm as compared to 0.61 ppm after 3 days of exposure at the disposal site and 0.57 ppm after 7 days at the reference site.

### Mussels

18. The mercury content of mussels ranged between 0.01 and 0.03 ppm with a mean of 0.02 ppm for the predisposal specimens and also for the specimens from both sites (Table C4). No difference was observed in the mercury content of the animals collected before disposal and those collected 1, 2, and 3 weeks after disposal. These findings agree with a baseline study of trace heavy metals in biota of Puget Sound in which mussels contained a mean mercury level of 0.02 ppm<sup>21</sup> (a factor of 0.165 was used to convert original values from dry-weight basis to wet-weight basis).

19. The chromium content found in mussels ranged between 0.21 and 0.51 ppm with a mean of 0.44 ppm for the predisposal samples and 0.33 and 0.34 ppm for the disposal and west reference sites, respectively. These values are within the range of 0.15-1.96 ppm chromium found by other researchers in mussels collected from various areas in Puget Sound.<sup>21</sup> The chromium content of animals collected at 1, 2, and 3 weeks from the disposal site were 0.37, 0.34, and 0.29 ppm, respectively, and those from the west reference site were 0.38, 0.34, and 0.30 ppm, respectively. The data showed a gradual decrease in the chromium content of the specimens from both sites as exposure time progressed. The decrease in chromium content of the mussels may be due to a seasonal decrease in the chromium content in the water of Elliott Bay. In general, concentration of heavy metals in bivalve mollusks changes with their environment.<sup>22</sup> Comparison of chromium levels in animals from the disposal site with those from the reference site clearly showed no effect of open-water disposal on chromium levels.

### Sea cucumbers

20. Sea cucumbers contained very low levels of mercury that ranged from 0.01 to 0.02 ppm with a mean of 0.01 ppm for predisposal samples and also for samples from both sites (Table C5). It was apparent that there was no difference in the mercury levels in these specimens.

21. The chromium content of sea cucumbers ranged from 0.18 to 0.36 ppm with a mean of 0.32 ppm for the predisposal specimens and 0.26, and 0.24 ppm for the disposal and west reference sites, respectively (Table C5). After 1 week of exposure, chromium levels for specimens from both sites were slightly lower. No further changes were observed at the second- and third-week sampling.

#### English sole

22. The mean mercury levels of English sole from the disposal and west reference sites were 0.08 and 0.07 ppm, respectively, for specimens collected before disposal, and 0.06 ppm at each site after 2 weeks exposure (Table C6). Specimens collected from the west reference site at 5 and 39 weeks contained lower levels of mercury than the predisposal and two-week samples.

23. The chromium content of English sole ranged between 0.40 and 0.62 ppm (Table C6). No significant difference was found in the chromium levels at the two sites up to 5 weeks after disposal.

#### Alaska pink shrimp

24. There was no significant difference in the mean mercury content of the postdisposal samples collected from the disposal and west reference sites (Table C7). The mean mercury levels in specimens from the disposal and west reference sites were slightly lower at 27 weeks than at 0 weeks. At 0 weeks exposure, the mean mercury levels in specimens from the disposal and west reference sites were 0.08 and 0.06 ppm, respectively, as compared to 0.04 and 0.05 ppm after 27 weeks exposure.

25. The specimens from the disposal site had a high chromium level of 0.83 ppm at 0 weeks and a low of 0.50 ppm at 27 weeks (Table C7). The specimens from the west reference site had a high of 0.67 ppm at 14 weeks and a low of 0.58 ppm at 27 weeks, but showed no definite trend. It is questionable whether the variations observed in the

chromium levels in Alaska pink shrimp can be attributed to open-water disposal of contaminated dredged material or to normal sample variation.

#### Oregon pink shrimp

26. No difference was observed in the mean mercury content of the specimens collected from the west reference site at 5 and 39 weeks. The one sample collected at 27 weeks contained slightly less mercury than the others. The specimens ranged from 0.07 to 0.08 ppm with a mean of 0.08 ppm (Table C8). Specimens were not available from the disposal site.

27. The specimens collected at 5, 27, and 39 weeks contained chromium levels that ranged from 0.50 to 0.69 ppm with a mean of 0.57 ppm. The 27-week sample contained slightly lower chromium content than the 5- or 39-week samples (Table C8). These data suggested normal sample variation.

#### Conclusion

28. The results of these studies show that open-water disposal of the dredged material from the Duwamish Waterway into Elliott Bay had no apparent effect upon the mercury and chromium content of spot shrimp, mussels, sea cucumbers, English sole, and Alaska and Oregon pink shrimp. No significant difference was noted in the mercury or chromium content between animals from the disposal and reference sites. Generally, the level of the two elements decreased slightly with exposure time. These changes were observed in the specimens from both sites with exposure time, suggesting that the observed changes resulted from normal or seasonal variations. The mercury and chromium levels found in mussels and English sole were in good agreement with the findings of other researchers who have studied these species taken from various locations in Puget Sound.

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Table C1  
Reproducibility of Mercury Analysis in Marine Organisms

<u>Species</u>	<u>Sample</u>	<u>Mercury, ppm</u>		
		<u>Analysis</u> <u>No. 1</u>	<u>Analysis</u> <u>No. 2</u>	<u>Mean</u>
Mussel	1	0.02	0.02	0.02
	2	0.02	0.02	0.02
	3	0.02	0.02	0.02
	4	0.03	0.03	0.03
Sea cucumber	1	0.01	0.01	0.01
	2	0.01	0.01	0.01
	3	0.01	0.01	0.01
	4	0.01	0.01	0.01
English sole	1	0.04	0.04	0.04
	2	0.06	0.06	0.06
	3	0.04	0.04	0.04
Spot shrimp	1	0.06	0.06	0.06
	2	0.06	0.06	0.06
Pink shrimp	1	0.06	0.06	0.06
	2	0.04	0.04	0.04
	3	0.07	0.08	0.08
	4	0.08	0.08	0.08
	5	0.06	0.06	0.06

Table C2  
Reproducibility of Chromium Analysis in Marine Organisms

<u>Species</u>	<u>Sample</u>	<u>Chromium, ppm</u>		
		<u>Analysis No. 1</u>	<u>Analysis No. 2</u>	<u>Mean</u>
Mussel	1	0.48	0.49	0.48
	2	0.39	0.39	0.39
	3	0.46	0.51	0.48
	4	0.33	0.39	0.36
Sea cucumber	1	0.33	0.38	0.36
	2	0.33	0.33	0.33
	3	0.29	0.34	0.32
	4	0.28	0.36	0.32
English sole	1	0.47	0.45	0.46
	2	0.41	0.45	0.43
	3	0.61	0.64	0.62
Spot shrimp	1	0.71	0.65	0.68
	2	0.63	0.64	0.64
	3	0.58	0.53	0.56
Pink shrimp	1	0.58	0.58	0.58
	2	0.61	0.63	0.62
	3	0.54	0.57	0.56
	4	0.62	0.56	0.59

Table C3  
Mercury and Chromium Concentrations in Spot Shrimp

Exposure (days)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal	West	Disposal	West
		Site	Reference	Site	Reference
		<u>Predisposal</u>			
0	1	0.06	0.06	0.68	0.68
	2	0.07	0.07	0.66	0.66
	3	0.06	0.06	0.60	0.60
	4	0.07	0.07	0.61	0.61
	$\bar{X}$	0.06	0.06	0.64	0.64
	SD	0.006	0.006	0.039	0.039
	RSD, % *	8.9	8.9	6.0	6.0
		<u>During Disposal</u>			
3	1	0.06	----	0.64	----
	2	0.06	----	0.56	----
	3	0.07	----	0.64	----
	4	0.06	----	0.62	----
	$\bar{X}$	0.06	----	0.62	----
	SD	0.005	----	0.038	----
	RSD, %	9.6	----	6.2	----
3	1	0.06	----	0.63	----
	2	0.06	----	0.63	----
	3	0.07	----	0.61	----
	4	0.07	----	0.56	----
	$\bar{X}$	0.06	----	0.61	----
	SD	0.006	----	0.033	----
	RSD, %	8.9	----	5.4	----
7	1	----	0.07	----	0.56
	2	----	0.07	----	0.59
	3	----	0.08	----	0.57
	4	----	0.06	----	0.55
	$\bar{X}$	----	0.07	----	0.57
	SD	----	0.008	----	0.017
	RSD, %	----	11.7	----	3.0

\* RSD = relative standard deviation.

Table C4  
Mercury and Chromium Concentrations in Mussels

Exposure (weeks)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal	West	Disposal	West
		Site	Reference	Site	Reference
<u>Predisposal</u>					
0	1	0.02	0.02	0.48	0.48
	2	0.02	0.02	0.39	0.39
	3	0.02	0.02	0.46	0.46
	4	0.02	0.02	0.41	0.41
	$\bar{X}$	0.02	0.02	0.44	0.44
	SD	0	0	0.042	0.042
	RSD, %	0	0	9.7	9.7
<u>Postdisposal</u>					
1	1	0.02	0.03	0.48	0.51
	2	0.02	0.03	0.37	0.36
	3	0.01	0.02	0.28	0.32
	4	0.02	0.02	0.35	0.31
	$\bar{X}$	0.02	0.02	0.37	0.38
	SD	0.005	0.006	0.083	0.092
	RSD, %	27.8	23.1	22.4	24.7
2	1	0.02	0.02	0.37	0.25
	2	0.02	0.02	0.32	0.35
	3	0.02	0.02	0.36	0.42
	4	0.02	0.02	0.30	0.36
	$\bar{X}$	0.02	0.02	0.34	0.34
	SD	0	0	0.033	0.700
	RSD, %	0	0	9.8	20.4
3	1	0.02	0.01	0.27	0.32
	2	0.02	0.02	0.47	0.31
	3	0.02	0.02	0.22	0.33
	4	0.02	0.02	0.21	0.26
	$\bar{X}$	0.02	0.02	0.29	0.30
	SD	0	0.005	0.121	0.031
	RSD, %	0	27.8	41.5	10.2

Table C5  
Mercury and Chromium Concentrations in Sea Cucumbers

Exposure (weeks)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal	West	Disposal	West
		Site	Reference	Site	Reference
<u>Predisposal</u>					
0	1	0.01	0.01	0.36	0.36
	2	0.01	0.01	0.27	0.27
	3	0.01	0.01	0.32	0.32
	4	0.01	0.01	0.33	0.33
	$\bar{X}$	0.01	0.01	0.32	0.32
	SD	0	0	0.037	0.037
RSD, %	0	0	11.7	11.7	
<u>Postdisposal</u>					
1	1	0.01	0.01	0.33	0.32
	2	0.01	0.02	0.32	0.24
	3	0.01	0.01	0.22	0.22
	4	0.01	0.01	0.19	0.20
	$\bar{X}$	0.01	0.01	0.26	0.24
	SD	0	0.005	0.070	0.052
	RSD, %	0	41.7	26.6	21.5
2	1	0.01	0.01	0.27	0.30
	2	0.01	0.01	0.32	0.22
	3	0.01	0.01	0.18	0.26
	4	0.01	0.01	0.25	0.19
	$\bar{X}$	0.01	0.01	0.26	0.24
	SD	0	0	0.058	0.048
	RSD, %	0	0	22.8	19.8
3	1	0.01	0.01	0.28	0.24
	2	0.01	0.01	0.19	0.28
	3	0.01	0.01	0.27	0.22
	4	0.01	0.01	0.31	0.24
	$\bar{X}$	0.01	0.01	0.26	0.24
	SD	0	0	0.051	0.025
	RSD, %	0	0	19.6	10.3

Table C6  
Mercury and Chromium Concentrations in English Sole

Exposure (weeks)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal	West	Disposal	West
		Site	Reference	Site	Reference
		<u>Predisposal</u>			
0	1	0.08	0.06	0.43	0.44
	2	0.07	0.08	0.46	0.44
	3	0.08	0.07	0.44	0.42
	$\bar{X}$	0.08	0.07	0.44	0.43
	SD	0.006	0.010	0.015	0.012
	RSD, %	7.5	14.3	3.4	2.7
		<u>Postdisposal</u>			
2	1	0.04	0.06	0.46	0.43
	2	0.10	0.06	0.46	0.45
	3	0.05	0.07	0.52	0.42
	$\bar{X}$	0.06	0.06	0.48	0.43
	SD	0.032	0.006	0.035	0.015
	RSD, %	51.0	9.2	7.2	3.5
5	1	----	0.03	----	0.61
	2	----	0.03	----	0.41
	3	----	0.04	----	0.40
	$\bar{X}$	----	0.03	----	0.47
	SD	----	0.006	----	0.118
	RSD, %	----	17.5	----	25.0
39	1	----	0.04	----	0.62

Table C7  
Mercury and Chromium Concentrations in Alaska Pink Shrimp

Exposure (weeks)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal	West	Disposal	West
		Site	Reference	Site	Reference
<u>Predisposal</u>					
0	1	0.08*	0.05	0.72*	0.74
	2	0.08*	0.06	0.91*	0.59
	3	0.07*	0.06	0.85*	0.55
	$\bar{X}$	0.08	0.06	0.83	0.63
	SD	0.006	0.006	0.097	0.100
	RSD, %	7.5	10.1	11.7	16.0
<u>Postdisposal</u>					
2	1	0.06	0.07	0.58	0.62
	2	0.06	0.05	0.68	0.53
	3	0.06	0.07	0.78	0.70
	$\bar{X}$	0.06	0.06	0.68	0.62
	SD	0	0.012	0.100	0.085
	RSD, %	0	18.3	14.7	13.6
5	1	0.07	----	0.51	----
	2	0.07	----	0.80	----
	3	0.07	----	0.58	----
	$\bar{X}$	0.07	----	0.63	----
	SD	0	----	0.151	----
	RSD, %	0	----	24.0	----
14	1	0.05	0.07	0.56	0.56
	2	0.05	0.06	0.58	0.60
	3	0.05	0.06	0.50	0.85
	$\bar{X}$	0.05	0.06	0.55	0.67
	SD	0	0.006	0.042	0.157
	RSD, %	0	9.2	6.6	23.5
27	1	0.04	0.04	0.43	0.61
	2	0.04	0.06	0.52	0.54
	3	0.05	----	0.54	----
	$\bar{X}$	0.04	0.05	0.50	0.58
	SD	0.006	0.014	0.059	0.049
	RSD, %	13.4	28.3	11.8	8.6
39	1	0.04	0.05	0.62	0.70

\* A mixture of Alaska and Oregon pink shrimp, predominantly Alaska pink shrimp.

Table C8  
Mercury and Chromium Concentrations in Oregon Pink Shrimp

Exposure (weeks)	Sample	Mercury, ppm		Chromium, ppm	
		Disposal Site	West Reference	Disposal Site	West Reference
		<u>Postdisposal</u>			
5	1	----	0.08	----	0.56
	2	----	0.08	----	0.53
	3	----	0.07	----	0.53
	$\bar{X}$	----	0.08	----	0.54
	SD	----	0.006	----	0.017
	RSD, %	----	7.5	----	3.5
27	1	----	0.07	----	0.50
39	1	----	0.08	----	0.69
	2	----	0.08	----	0.61
	3	----	0.07	----	0.60
	$\bar{X}$	----	0.08	----	0.63
	SD	----	0.006	----	0.049
	RSD, %	----	7.5	----	7.8

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Aquatic disposal field investigations, Duwamish Waterway disposal site, Puget Sound, Washington; Appendix C: Effects of dredged material disposal on the concentration of mercury and chromium in several species of marine animals / by Fuad M. Teeny and Alice S. Hall, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, Washington. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.

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References: p. 13-14.

(Continued on next card)

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1. Chromium. 2. Disposal areas. 3. Duwamish Waterway. 4. Dredged material disposal. 5. Marine animals. 6. Mercury. 7. Waste disposal sites. I. Hall, Alice S., joint author. II. United States. Army. Corps of Engineers. III. United States. National Marine Fisheries Service. Northwest and Alaska Fisheries Center. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-24, Appendix C. TA7.W34 no.D-77-24 Appendix C